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Supplementary information

Limited increases in savanna carbon stocks over decades of fire suppression

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Supplementary information

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Supplementary information

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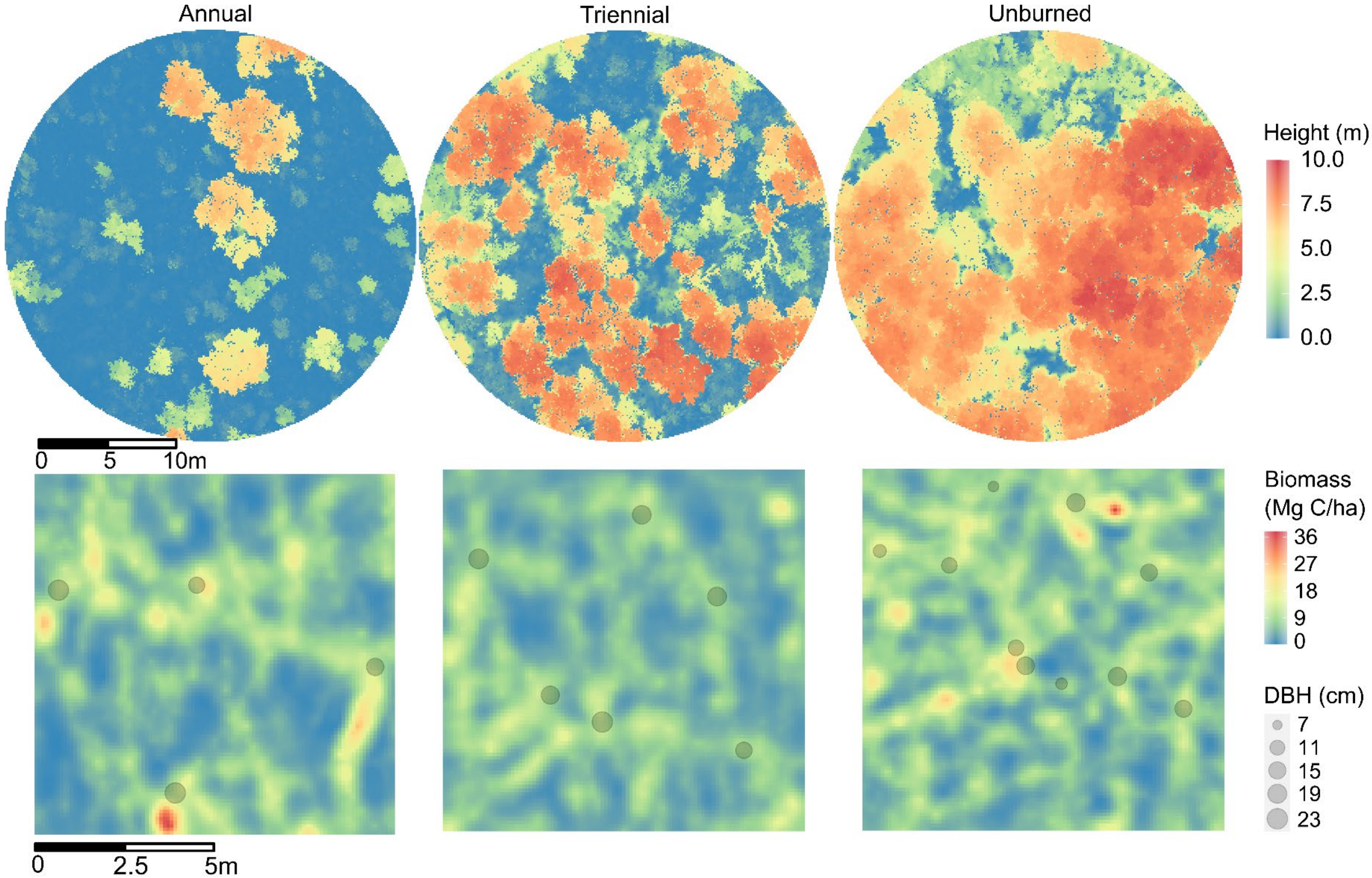
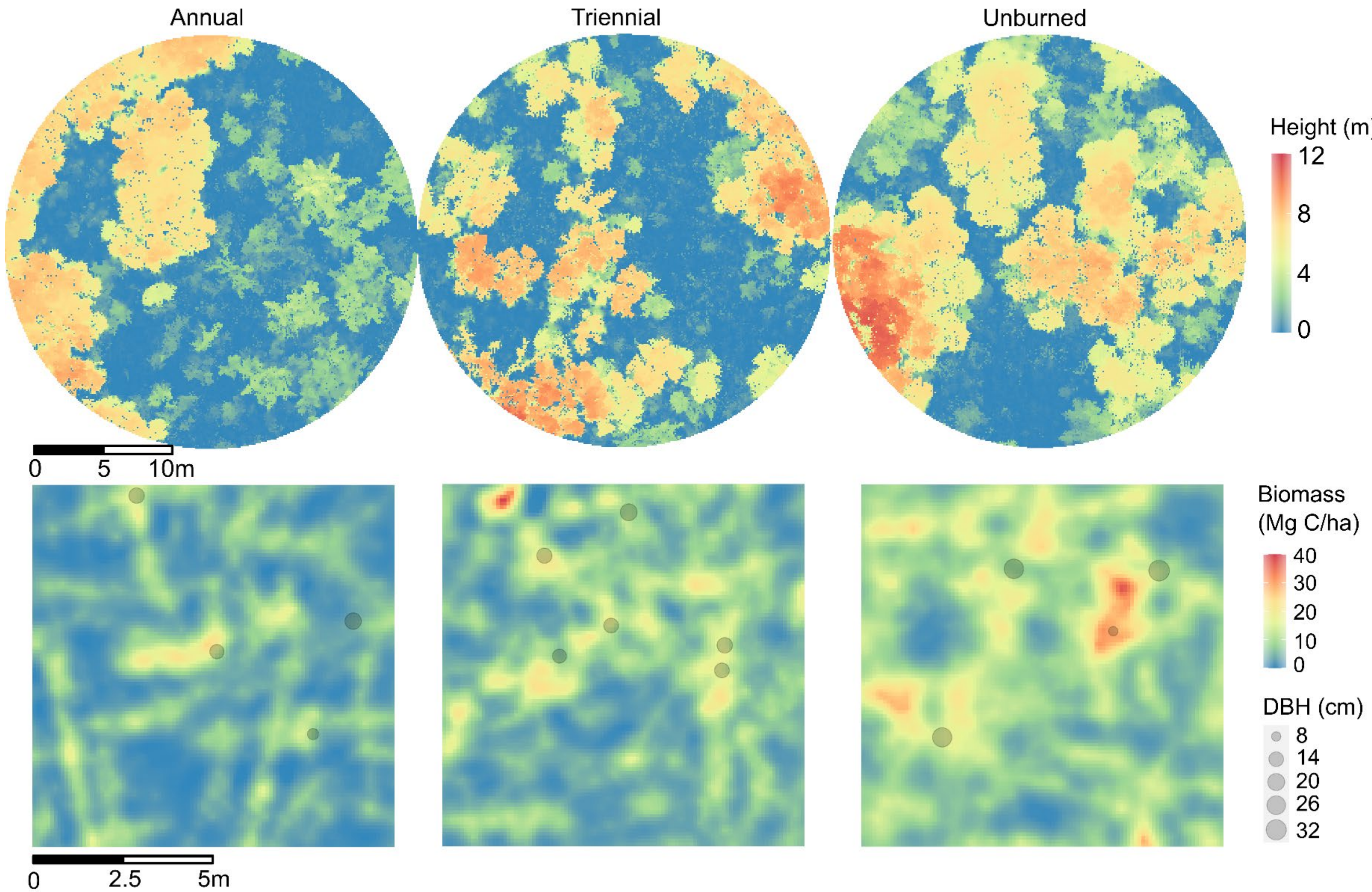
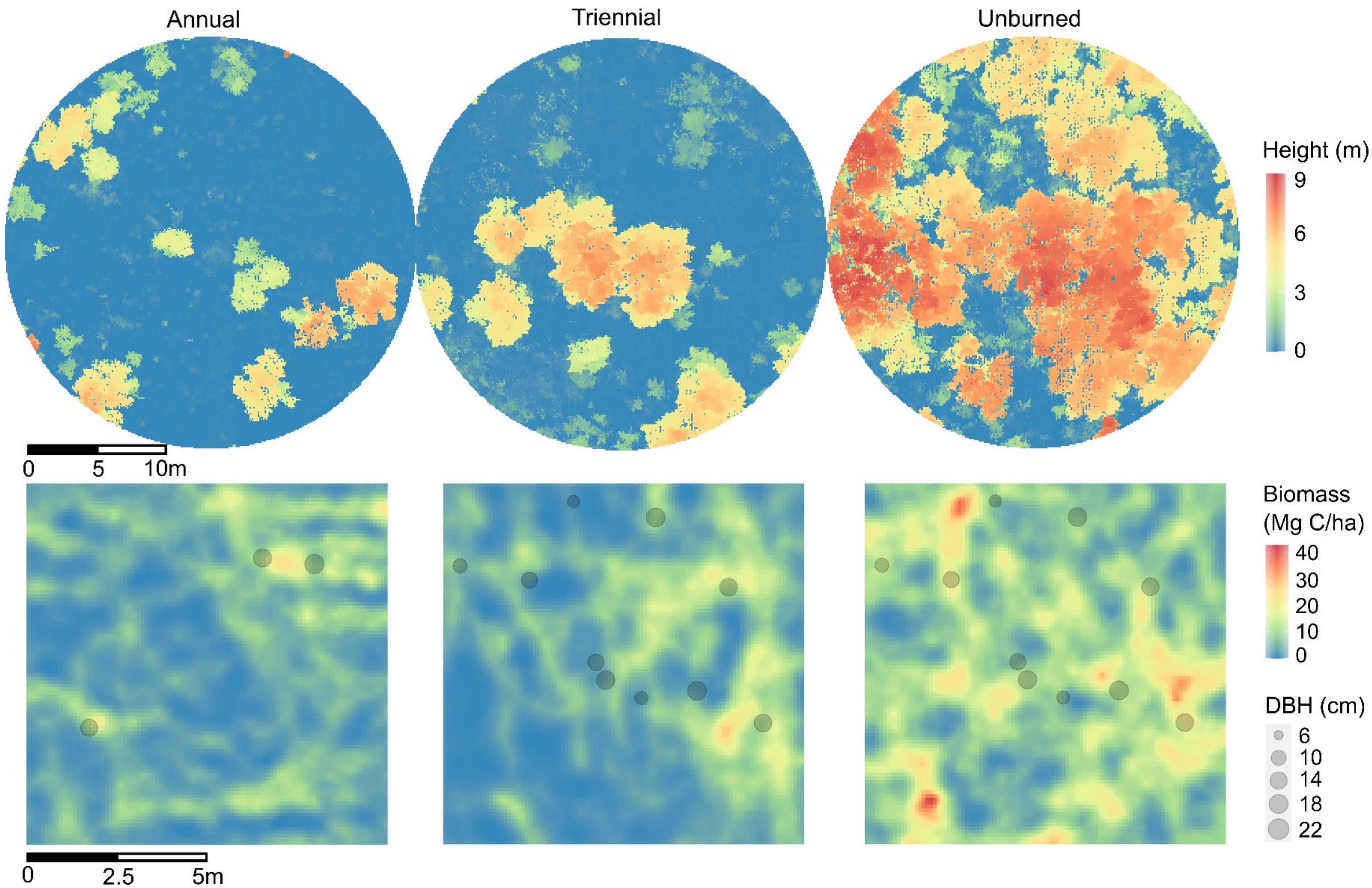


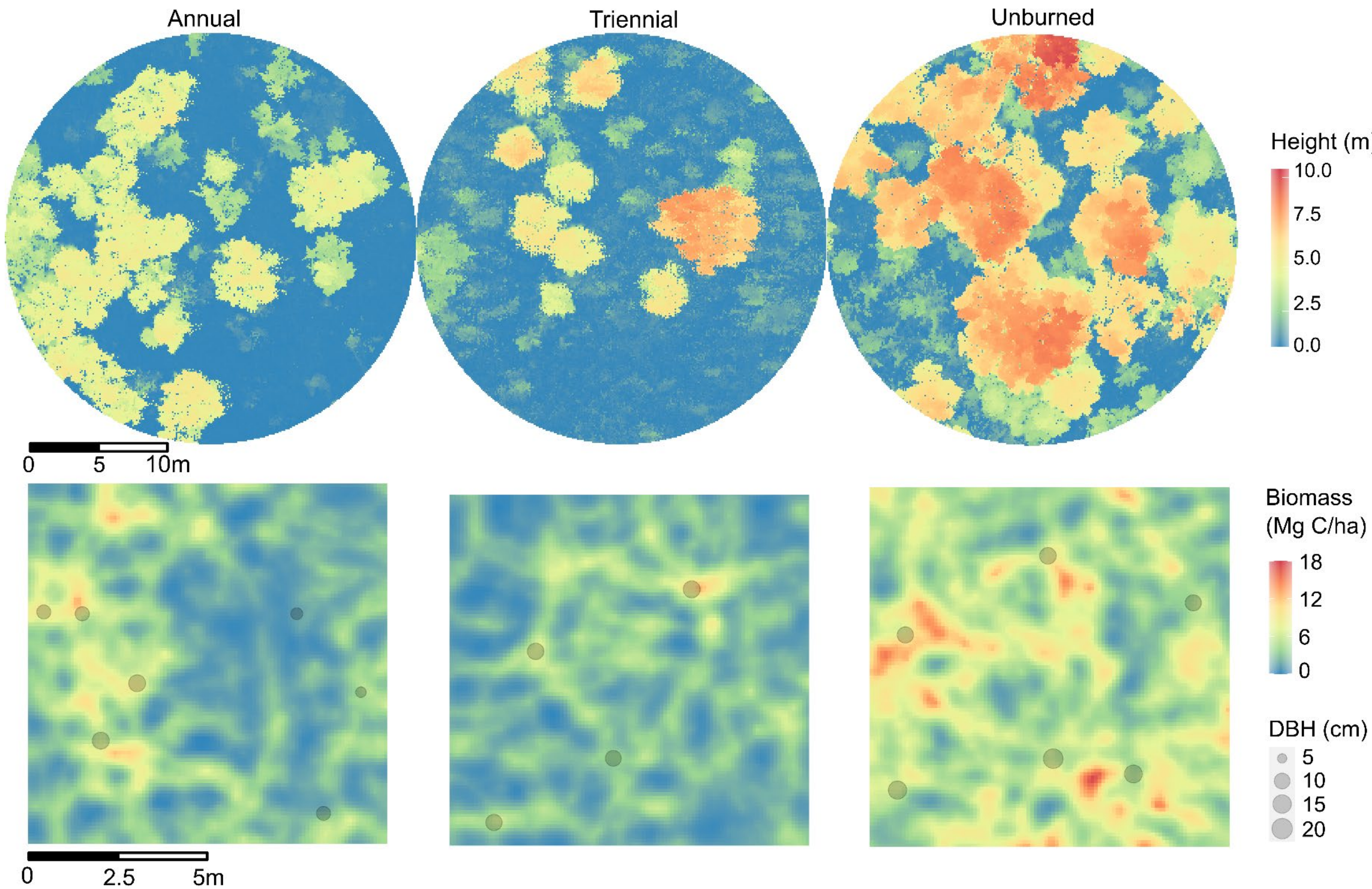
Supplementary Fig. 1 | Tree canopy height and coarse lateral root biomass across fire treatments at the Fayi String within the Pretoriuskop landscape in Kruger National Park, South Africa. Tree canopy height within each 30 m diameter plot was measured using light detection and ranging (LiDAR) and coarse lateral root biomass within each 10 m × 10 m plot was estimated from ground penetrating radar (GPR). The 10 m × 10 m plot is approximately located at the center of the 30 m diameter plot. The points within the 10 m × 10 m plot indicate locations of trees with diameter at breast height (DBH) > 5 cm and are scaled with DBH.



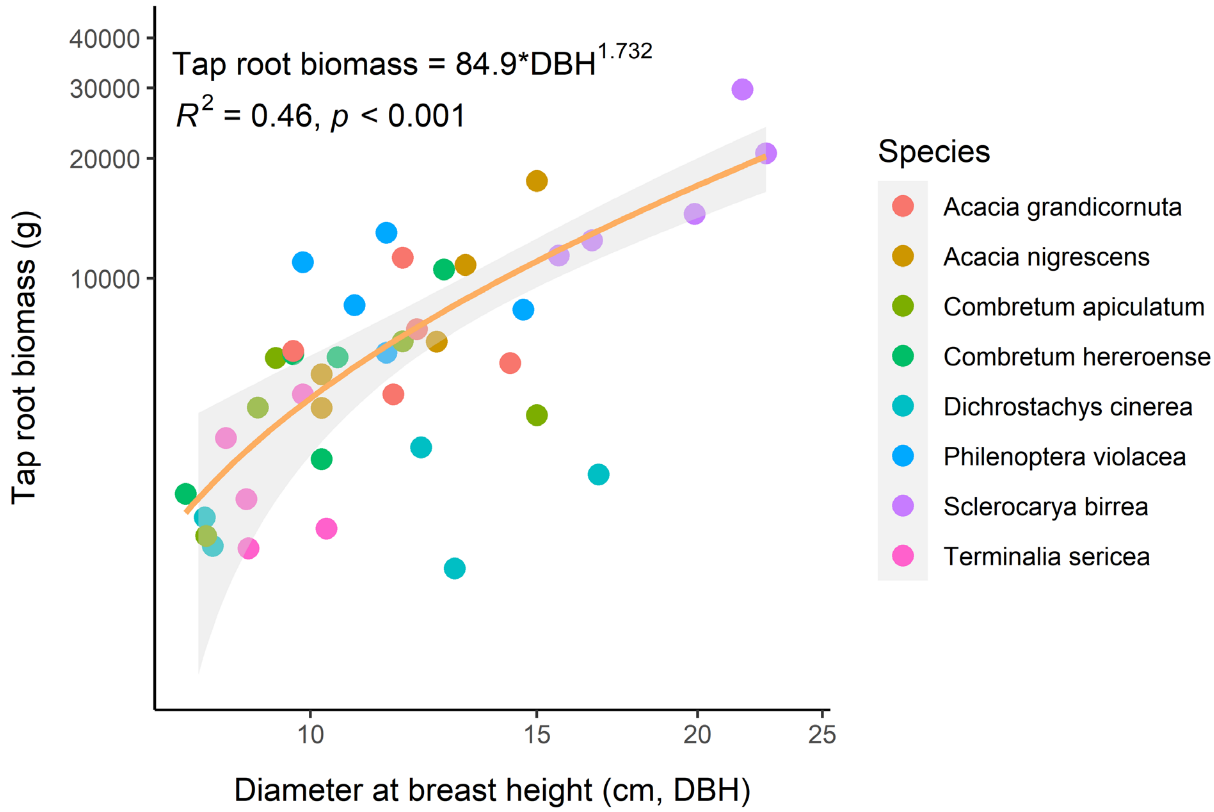
Supplementary Fig. 2 | Tree canopy height and coarse lateral root biomass across fire treatments at the Kambeni String within the Pretoriuskop landscape in Kruger National Park, South Africa. Tree canopy height within each 30 m diameter plot was measured using light detection and ranging (LiDAR) and coarse lateral root biomass within each 10 m × 10 m plot was estimated from ground penetrating radar (GPR). The 10 m × 10 m plot is approximately located at the center of the 30 m diameter plot. The points within the 10 m × 10 m plot indicate locations of trees with diameter at breast height (DBH) > 5 cm and are scaled with DBH.



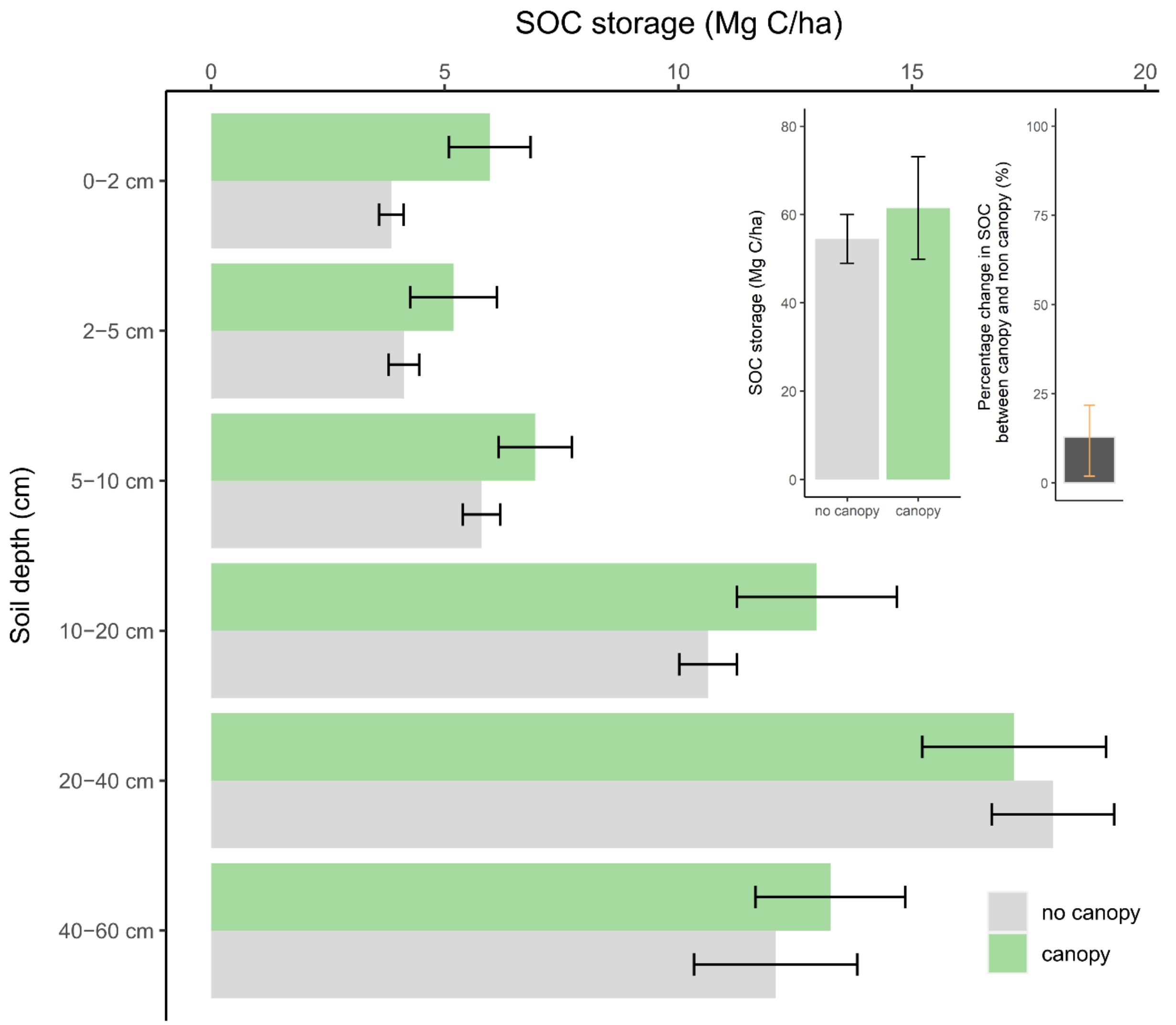
Supplementary Fig. 3 | Tree canopy height and coarse lateral root biomass across fire treatments at the Numbi String within the Pretoriuskop landscape in Kruger National Park, South Africa. Tree canopy height within each 30 m diameter plot was measured using light detection and ranging (LiDAR) and coarse lateral root biomass within each 10 m × 10 m plot was estimated from ground penetrating radar (GPR). The 10 m × 10 m plot is approximately located at the center of the 30 m diameter plot. The points within the 10 m × 10 m plot indicate locations of trees with diameter at breast height (DBH) > 5 cm and are scaled with DBH.



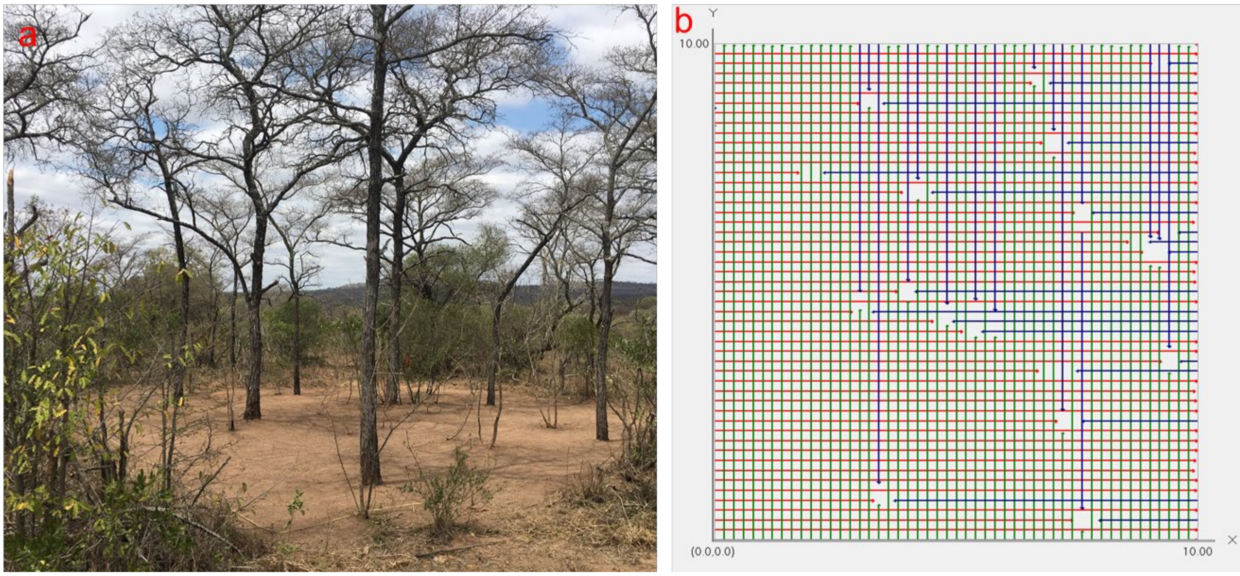
Supplementary Fig. 4 | Tree canopy height and coarse lateral root biomass across fire treatments at the Shabeni String within the Pretoriuskop landscape in Kruger National Park, South Africa. Tree canopy height within each 30 m diameter plot was measured using light detection and ranging (LiDAR) and coarse lateral root biomass within each 10 m × 10 m plot was estimated from ground penetrating radar (GPR). The 10 m × 10 m plot is approximately located at the center of the 30 m diameter plot. The points within the 10 m × 10 m plot indicate locations of trees with diameter at breast height (DBH) > 5 cm and are scaled with DBH.



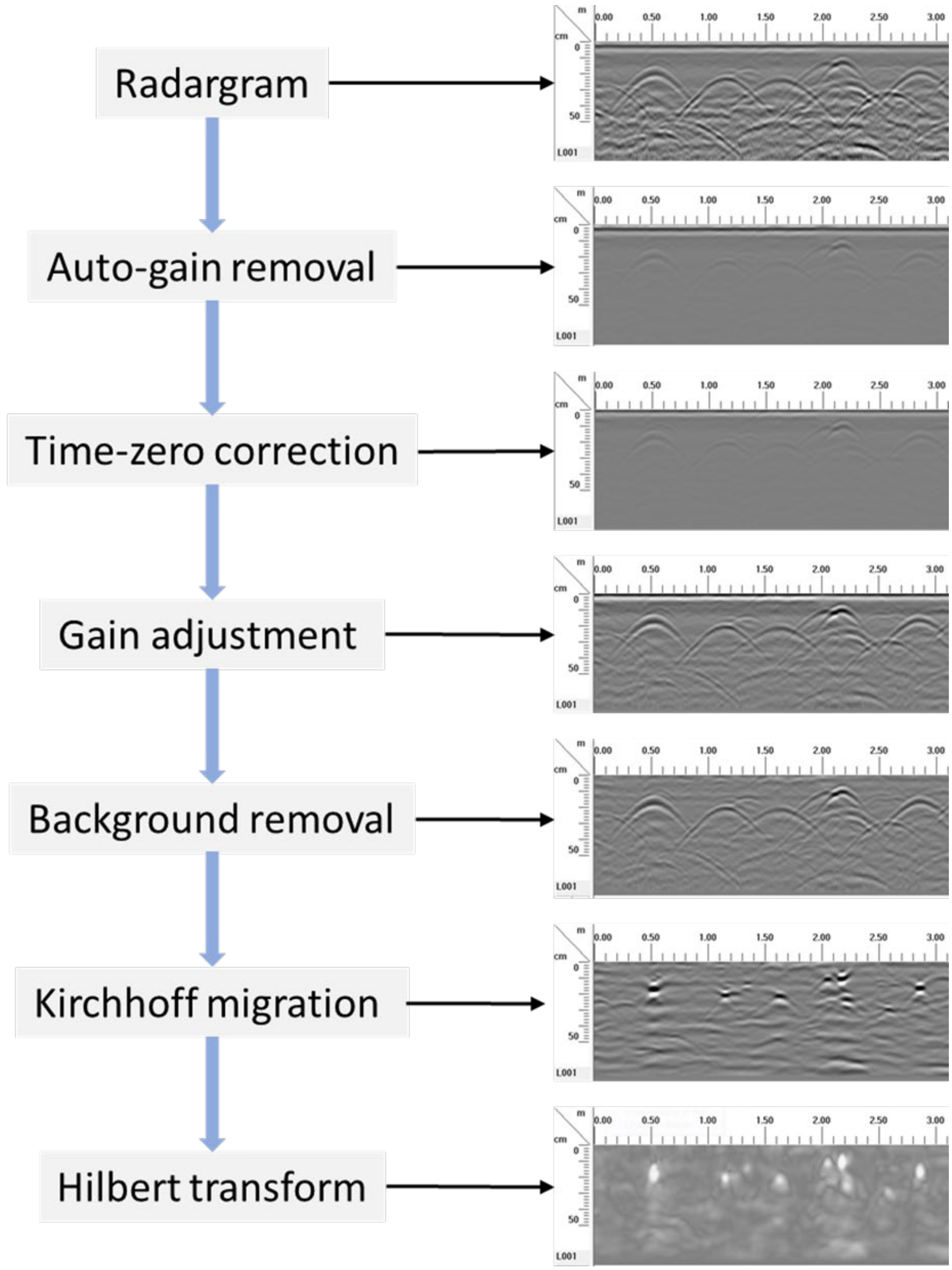
Supplementary Fig. 5 | Tree tap root biomass versus diameter at breast height (DBH) for common tree species in southern Kruger National Park. Tap root biomass within each 10 m × 10 m plot was estimated by fitting field measured DBH to this regression model. Shaded bands illustrating the 95% confidence interval of the fit. Data are from ref. [18].



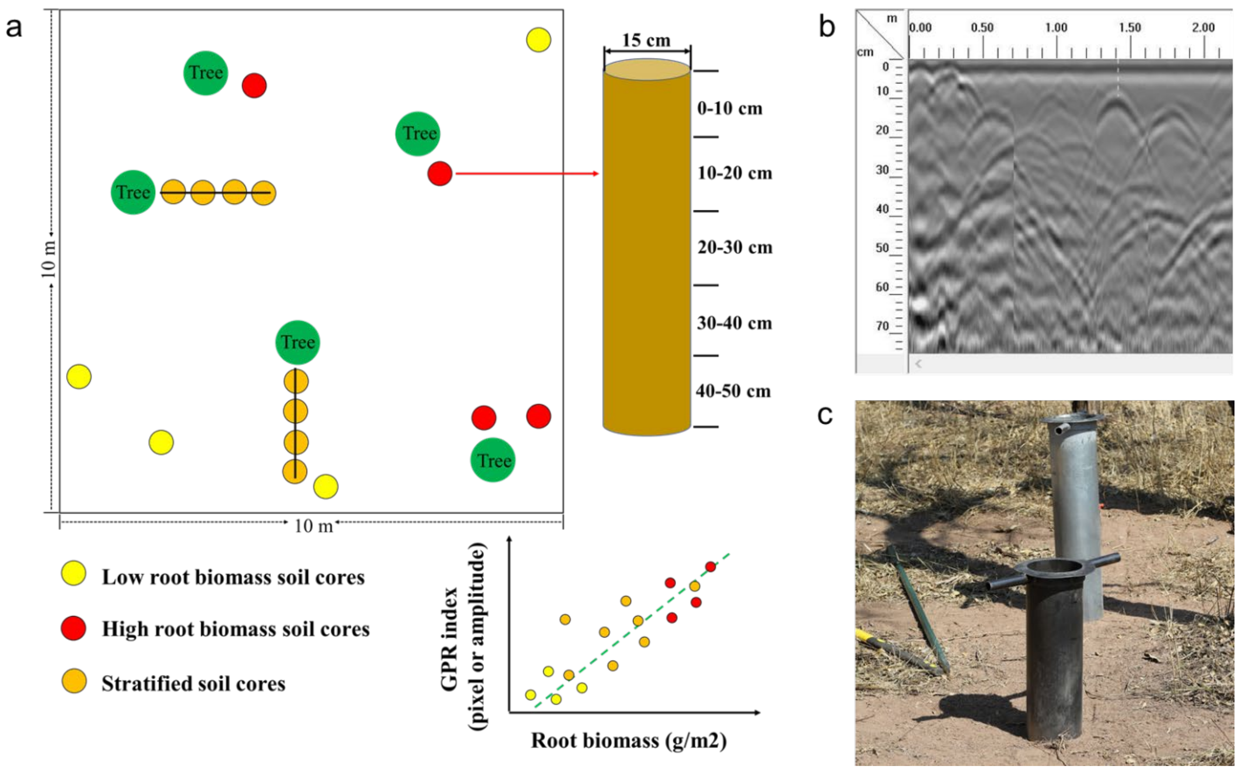
Supplementary Fig. 6 | Re-analysis of data from ref. [28] on soil organic carbon (SOC) storage (MgC/ha) under tree canopies and away from canopies throughout the 60-cm soil column at the Pretoriuskop landscape in Kruger National Park, South Africa. In our new data collection, we found that fire frequency had insignificant effects on SOC aggregated throughout the soil column, which seems at first glance to contrast with previous findings showing substantial fire effects on SOC under tree canopies with fire exclusion. However, this reanalysis shows that, changes are restricted only to very shallow soils and that total SOC does not change substantially with the presence of tree canopy in this savanna, irrespective to fire treatments. Inserts are total soil carbon storage under tree canopies and away from canopies and percentage change in soil carbon storage between canopy and no canopy. Soil carbon storage under tree canopies was 13 % higher than that away from canopies.



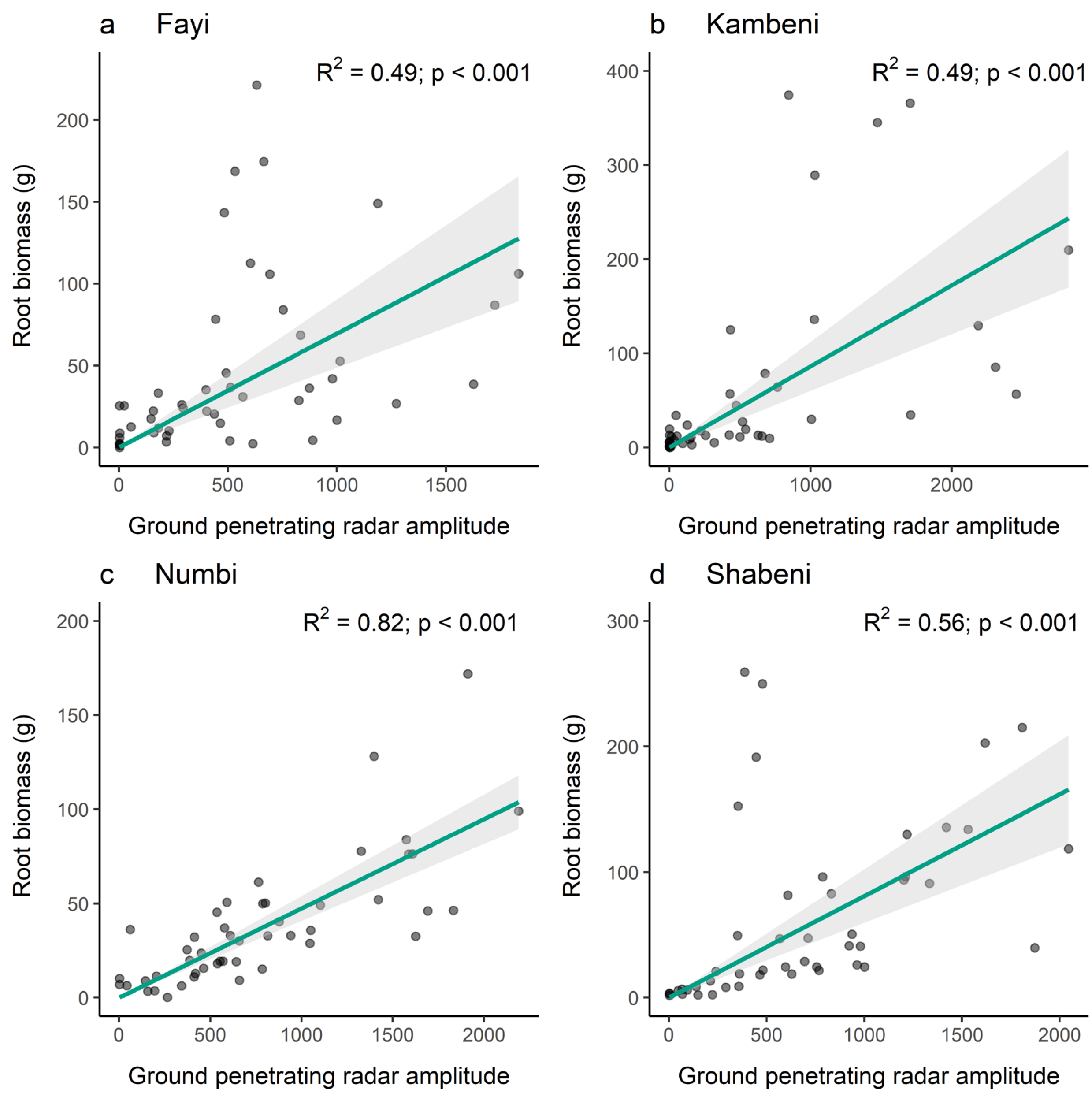
Supplementary Fig. 7 | Layout of a 10 m × 10 m plot for ground penetrating radar survey. (**a**) A photograph showing an unburned plot with the grass layer removed at the Pretoriuskop landscape of Kruger National Park, South Africa. (**b**) The layout of the ground penetrating radar (GPR) survey within the 10 m × 10 m plot with line spacing of 20 cm in both X and Y directions. Areas with no GPR survey lines indicate the locations of the trees.



Supplementary Fig. 8 | A schematic frame showing steps in processing ground penetrating radargrams in Radan 7 software and examples of processed radargrams at each step. See the *Methods* section for more details.



Supplementary Fig. 9 | A schematic frame showing the coring method for root biomass estimation from ground penetrating radar. (**a**) A schematic frame showing the strategy to select locations for developing the regression line used to estimate root biomass from ground penetrating radar. (**b**) An example of the ground penetrating radar with the marked location (dashed white line). (**c**) Soil cores (15 cm in diameter and 50 cm in length) used to retrieve roots at each selected location within the 10 m × 10 m plot. See the *Methods* section for more details.



Supplementary Fig. 10 | Root biomass versus ground penetrating radar amplitude used to estimate plot-level coarse lateral root biomass at each string within Pretoriuskop landscape in Kruger National Park, South Africa. The regression line indicates the significant linear fit and shaded bands illustrate the 95% confidence interval of the linear fit.

Supplementary Table 1 | Soil and vegetation characteristics for different fire treatments (*i.e.*, annual, triennial, and unburned) within the Pretoriuskop landscape in Kruger National Park, South Africa. Values for soil parameters were averaged over the 60-cm soil column. Diameter at breast height (DBH) and stem density were calculated based on vegetation survey data within the10 m × 10 plots. Tree height and cover were measured using light detection and ranging data within the 30-m diameter plots (see Supplementary Figs. 1-4). Values are mean ± standard errors (n = 4).

Treatment	Soil sand content (%)	Soil bulk density (g/cm^3)	Soil $\delta^{13}C$ (‰)	Soil organic carbon (%)	DBH (cm)	Stem density (stems/ha)	Tree height (m)	Tree cover (%)
Annual	90.1 ± 2.4	1.58 ± 0.03	-16.3 ± 0.60	0.33 ± 0.03	14.2 ± 2.16	2300 ± 318	3.89 ± 0.16	35.5 ± 9.05
Triennial	90.0 ± 1.6	1.57 ± 0.01	-17.0 ± 0.70	0.37 ± 0.04	14.1 ± 1.74	1950 ± 507	4.35 ± 0.57	49.0 ± 9.59
Unburned	89.4 ± 1.0	1.57 ± 0.02	-17.7 ± 0.32	0.37 ± 0.03	16.6 ± 2.79	2875 ± 620	5.52 ± 0.31	79.9 ± 4.80

Supplementary Table 2 | Mean and standard error (SE, n = 4) for each carbon pool (Mg C/ha) across different fire treatments (*i.e.*, annual, triennial, and unburned) within the Pretoriuskop landscape in Kruger National Park, South Africa.

Treatment	Component	Carbon pool	Mean (Mg C/ha)	SE
Annual	aboveground	Woody plants	11.12	2.59
Triennial	aboveground	Woody plants	23.57	8.60
Unburned	aboveground	Woody plants	41.67	3.28
Annual	aboveground	Grasses	1.66	0.15
Triennial	aboveground	Grasses	2.45	0.13
Unburned	aboveground	Grasses	2.59	0.16
Annual	belowground	Grass fine roots	3.60	0.25
Triennial	belowground	Grass fine roots	3.03	0.34
Unburned	belowground	Grass fine roots	3.00	0.20
Annual	belowground	Woody fine roots	1.74	0.36
Triennial	belowground	Woody fine roots	1.73	0.26
Unburned	belowground	Woody fine roots	2.47	0.18
Annual	belowground	Woody coarse roots	4.51	0.61
Triennial	belowground	Woody coarse roots	4.99	0.91
Unburned	belowground	Woody coarse roots	8.12	1.08
Annual	belowground	Woody tap roots	1.82	0.33
Triennial	belowground	Woody tap roots	2.71	0.61
Unburned	belowground	Woody tap roots	3.88	0.59
Annual	belowground	C3-derived SOC	9.54	1.42
Triennial	belowground	C3-derived SOC	11.88	1.34
Unburned	belowground	C3-derived SOC	15.82	0.56
Annual	belowground	C4-derived SOC	21.29	2.71
Triennial	belowground	C4-derived SOC	22.98	4.24
Unburned	belowground	C4-derived SOC	18.83	1.75

Supplementary Table 3 | Parameter settings used to scan each 10 m × 10 m plot with the ground penetrating radar SIR-4000 unit.

Parameter	Value
Samples/scan	512
Bits/sample	32
Scans/second	177
Scans/unit (m)	200
Units/mark(m)	0
Dielectric constant	4.0
Position	0
Range	11.11
Top surface (cm)	8.33
Depth (cm)	83.33
Low pass filter	3000
High pass filter	460

Supplementary Table 4 | Parameter settings used to collect high-resolution airborne light detection and ranging data using a Riegl VUX-1LR LiDAR sensor attached to a DJI M600 Pro UAV.

Parameter	Value
Flight altitude (m)	100
Flight speed (m/s)	8
Pulse repetition rate (kHz)	820
Scan rate (lines/second)	78.1
Field of view (°)	180
Spacing between survey transects (m)	114.25
Data overlap rate (%)	60
Laser beam divergence (mrad)	0.5